Si-PM based Beam Phase Measurement Technique for Cyclotron

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Introduction

For cyclotrons, beam phase measurement system is an essential tool for precise magnetic field tuning. Various non-intercepting capacitive and inductive phase measurement systems are used worldwide, which measures currents associated with the image charges produced by the accelerated beam. However, these methods needs intense beam bunches to produce the required phase information. In our present technique, we have used an interceptive probe comprising of plastic scintillator followed by optically coupled Si-PM diode. This technique provides the capability of phase detection even in very low beam current (in range of few nA). The technique was successfully tested in K=130 cyclotron at VECC.

Experimental Setup

The probe assembly consists of a plastic scintillator and Si-PM placed inside water cooled copper tube. For fast timing output SenSL Si-PM sensors have been used which are having a rise time of 300ps and a pulse width of 600ps. The Si-PM with 1x1 mm2 aperture was biased with less than 30 volt to achieve gain in order of 6 x 106. Earlier in VECC beam phase was measured for K=500 cyclotron using traditional photo-multipiler tubes (PMT) [1]. The main advantages of using Si-PM over traditional PMTs are low bias voltage and compact design. To get good time resolution, a BC418 plastic scintillator was chosen for its fast rise (decay) time of 0.5 (1.4) ns. The wavelength of maximum emission for BC418 is 391 nm matches with the spectral range of Si-PM (300-800 nm). Also, BC418 does not exhibit any self-radiation property and the scintillator is quite insensitive to other particles such as electrons, protons, alpha particles, neutron, etc. The scintillator is carefully optically coupled with the sensor for best optical efficiency.

The electrically isolated sensor assembly functions as phase probe whereas the copper cover is used for beam current measurement as well as sensor shielding. In Fig. 1 a portion of the plastic scintillator is visible inside a copper tube. Electrical wires and LCW pipes are connected via a feed through. A copper cap over the assembly creates a slit to pass a part of ion beam on the scintillator. The probe was operated in the acceleration zone of K=130 cyclotron. The scintillator probe was exposed with 3.3 MeV Alpha beam with current ranging from 100nA to 1.3 micro amp. A remotely operated linear drive system was used to move the probe along the cyclotron radius and the radial information was obtained from a position encoder attached with the probe assembly. The fast output signal of SiPM is taken outside the cyclotron via vacuum tight feed-through. A high bandwidth pulse amplifier was used to amplify the fast sensor pulses. The output of the amplifier gives pulse of rise time 5 nS and decay time 40 nS when seen in the oscilloscope. This processed signal was sent to control room via long BNC co-axial cable for data acquisition and further processing.

Fig. 1: Assembly of plastic scintillator and Si-PM inside copper tube

Data Acquisition & Processing

CAMAC-based data acquisition system and NIM electronics were used to extract the phase information from the sensor output signal. The processed fast output signal of Si-PM is initially amplified using a 50-Ohm matched high bandwidth amplifier. This output is sent to Constant Fraction Discriminator (CFD) module to generate the timing pulse that was used as the START signal for the Time-to-Amplitude Converter (TAC). The STOP signal for the TAC was generated from cyclotron RF by feeding it into Leading Edge Discriminator (LED) module. The full scale time interval of TAC was set as 200 ns as one full cycle of 6 MHz RF signal is equivalent to 160 ns. The analog output of the TAC (10 V full scale), representing the time difference between the Si-PM output and the RF signal, was digitized by the CAMAC peak sensing ADC suitable for high resolution spectroscopic applications. Fig. 2 shows the experimental setup of this technique which has been used for measuring beam phase at K=130 Room Temperature Cyclotron.

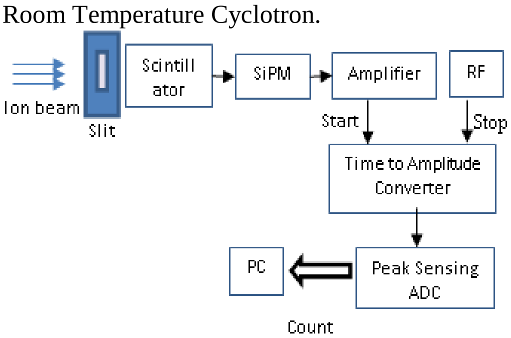

Fig. 2: Block Diagram of Beam phase measurement experimental setup

Results

Relative phase of the ion beam w.r.t. RF signal was measured using nuclear data acquisition system. This was done at various radial position of the probe inside cyclotron. Figure 3 shows the screenshot of the SiPM Fast output signal captured in a digital oscilloscope. We can see that in every RF cycle, a signal pulse is observed. The phase difference between the zero crossing of RF signal and SiPM signal peak gives the relative beam phase. Figure 4 shows the variation of relative beam phase with radius.

Fig. 3: SiPM Fast output signal

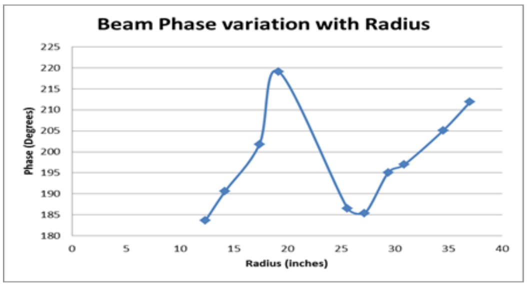

Fig. 4: Variation of relative beam phase with radius.

Future Work

In future, it is proposed to develop a standalone desktop beam phase measurement instrument which can be used by the operators for regular beam tuning. For this the whole CAMAC based nuclear instrumentation rack will be replaced by a single desktop based high speed digitizer with FPGA where intelligent firmware might be written for data processing.

Conclusion

We have successfully tested the new beam phase measurement technique using Si-PM. Beam phase of the ion beam w.r.t. RF signal has been measured for various radial.

Acknowledgement

We thank all our colleagues, especially Shri Partha Dhara, Shri P.S. Chakrobarty, and Shri Amitava Roy for their valuable support during the experimentation.

References

[1] T. Bhattacharjee, et.al. "Development of a fast scintillator based beam phase measurement system for compact superconducting cyclotrons", Review of Scientific Instruments 84, 053303 (2013).